The City as a Subject for Ecological Research

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Keywords: plant diversity · exotic species · native species · human population · biosphere · urban climate · ecological characteristics of city · plant succession · growing season

Development and Importance of Ecological Investigations of the City as a Habitat

The city, in today's meaning for Central Europe, may be considered in the context of the development of modern technology and new energy sources. However, historically, cities may be considered in a narrower context, associated with the erratic increase in the world population. During the 1960s, the percentage of the population living in urban areas (i.e., areas with more than 20,000 inhabitants) was estimated to be 30% world wide (with the highest rates in North America 46%, Northwest Europe 54%, and Australia and New Zealand 65%). Thus, it is understandable that the most recent ecology has been focussed on the most densely populated regions (Aschenbrenner et al., 1970, 1972, 1974a,b: Dansereau 1970; Müller 1972, Fitter 1946, Kieran 1959, Miyawaki et al., 1971, Peters 1954, Rublowsky 1967).

The often repeated statement that each city is generally hostile to life, seems to be disproved in several ways. It was surprising to find that the first investigations of urban locations, showed that, with existing complications, purely anthropogenic biotopes can offer suitable habitats with characteristic species combinations. The species combinations of such habitats vary between industrial facilities, railways, ports, rubbish dumps, and so on, and may be different from those known from other habitats.

The flora of economically important species have been carefully researched in only three German cities: in Stuttgart (e.g. Kreh 1951), Leipzig (e.g. Gutte 1971), and in Berlin. The fauna has been researched in Hamburg, Kiel, Dortmund and Berlin (Erz 1964, Mulsow 1968, Weidner 1952, Wendland 1971). Ecology is now stronger and more systematic than in previous years; human influences in the conurbations have been studied, and research programs have been developed.

In recent years, ecological research projects have been initiated in Berlin (Kunick 1973, Runge 1973, Sukopp 1966, Zacharias 1972), and the preliminary results will be reported here.

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Translated from German and Originally Published in 1973 in Society for the Dissemination of Knowledge, Vienna
J.M. Marzluff et al., *Urban Ecology,*

Characteristics of the City Habitat

At first it may appear appropriate to consider the density of the human population as the decisive characteristic of a city, (whereas nearly every single "artificial" location has its analogy in nature; Strawinski 1966). However, classification of the city areas according to the residential density would result in a distorted picture, because in each city, one can observe a tendency for the depopulation of the city centre, with a decline from the most densely structured city centre to the garden suburbs. The number of people who actually use the area (such as workers and those traversing the area) is more difficult to determine.

An additional characteristic is the number and magnitude of anthropogenic interferences which exclude organisms (this occurs because the influences are arythmic; Erz 1964, Schweiger 1960). Furthermore, eutrophication is characteristic for human settlements in general, and is especially so in cities. Historically, the city of today can be seen as the end stage of a development, which develops from the village, to a small, and then middle-sized town.

Nevertheless, the total area does not appear to be a suitable criterion by which to understand the city. It is more of a mosaic habitat, formed from many diverse smaller biotopes. Certainly, the amount of technically fallow land is high (Hamburg and Bremen each 40%, Federal Republic of Germany on average 10%).

For biogeographical characteristics of a city, one can consider the original habitat of the apophytes, the number, immigration route, and geographical origin of the hemerochores, as well as the decline in plants. The composition of the synanthropic flora of the cities, reflects the influence of the adjacent environment, while under the apophytes, partly wood and bushes, and partly meadow plants, prevail (Krawiecowa & Rostanski 1971). In cities situated on bigger rivers, water and bank plants comprise approximately 10–17% of the apophytes.

In addition, the degree of development of a city (urbanisation, industrialisation, development of commerce and traffic), affects the spectrum of the synanthropic flora in the flowing characteristic ways:

Number of Non-Native Species

Falinksi (1971) compared different settlements from villages and towns (Table 1). This shows many difficulties in comparing material which originate from different settlements, with different borders, and reported by different authors. One would not expect a linear relationship between the number of inhabitants and the number of non-native species, if for example, important data on trade and traffic are missing. However, these data nevertheless do provide important clues. A map of the species number of non-native species in 47 places in Finland published by Erkamo (1959), states only the absolute species numbers of the non-native species, and does not place this in perspective with the total species number of the respective flora.

Among native plants on ruderal sites, perennials predominate, whereas amongst the non-natives, annual and biennial plants dominate (for example Misiewicz 1971 in Falinski 1971).

Table 1 Composition of the synanthropogenic flora of some villages and cities in Poland (including Ephemerophytes; in %)

	Native	Non-native
forest settlements	70–80	20–30
villages	70	30
towns	60–65	35–40
cities	50–60	40–50
large cities	30–50	50–70

Immigration of Non-Native Species

From the immigration of the introduced non-native species, one can distinguish between those that were intentionally introduced and cultivated by people, (and then spread beyond the cultivation area), and accidental introductions. A study of the species from 47 towns in Finland summarized by Erkamo (1959) showed that:

The accidental introductions (naturalised) form the largest group in most places. The accidental introductions are the largest group in only some (not all) large cities (Helsinki, Turku, Vaasa, Oulo, and Viipuri). For those that escaped from cultivation, generally the opposite applies: the accidental species are mostly (in 36 settlements out of 47 (69%)) more richly represented than are the naturalised ones. This is always so where the species pool is rich. The increase in species results from transportation and commerce.

The Geographic Origins of the Non-Native Species

Most the species which prefer old settlement areas originally had a southern distribution (Saarisalo-Taubert 1963). Some 3/5 of the archaeophytes and neophytes of the Berlin flora (on ruderal sites), most of which are annuals, are resident in, and spread from, warmer regions. Their settlement and establishment in moderate climatic regions of Europe, has been made possible through the climate of human settlements. The climatic effects of compact industrial areas and large cities result in a warmer and drier urban climate (Scholz 1960).

Reduction of Species Number

The change in habitat conditions results in a strong reduction in the species number. The flora in the surroundings of large cities and industrial areas shows a strong decline (Table 2). Because of the different methods of data acquisition in the individual areas, the table represents only an approximate picture of the loss of plant species (between 6 and 13% of the stock one hundred years ago).

Since 1859, some 114 species of ferns and flowering plants are presumed extinct or become extinct in Berlin. These represent a loss of about 12% of the native and archaeophytic species in one hundred years. Strong declines have been shown particularly by the plants of the pond weed family (Potamogetonaceae), with a loss of about 41% of their species number in one hundred years, and the orchid family (Orchidaceae).

In areas intensively changed by people, we do not know of a single case in which a plant would have disappeared due to natural causes. Under anthropogenic influences, habitat changes have caused more losses than direct collecting of plants. Stricker (1962) had emphasised the meaning of the change in habitats, by noting that the plants are not initially in decline, but rather it is a decline in habitats at which the plants can grow. Important factors accounting for the decline in

Table 2 Loss of species of ferns and flowering plants in the surroundings of some cities. a = archaeophytes; I = introduced; n = native; t = naturalized

Area	(km^2)	# of species	% extinct or missing
Paderborn	1,250	684 n	6
Stuttgart	1,000	1,080	4 n + 2 i
Berlin	884	965 n + a	12
Aargau	1,404	~1,300	16
South Lancashire	3,100	839 n + t	7.9

Table 3 Decline in plant communities in Berlin, illustrated by the number of extinct and presumed extinct ferns and flowering plants (modified after Sukopp, 1966)

Formation or Habitat	Total number of species	Species extinct or missing %	#	Change of surface, last 100 years
weeds of arable fields	90	17	15	–
bogs	61	16	10	–
waters	176	14	25	–
dry grassland	148	14	21	–
moist grassland	91	13	12	–
forest, hedges, skirt vegetation	236	10	23	
ruderal vegetation	121	7	8	+
meadows	42	0	0	–
Region of Berlin	965		114	

species of vascular plants are a lowering of groundwater, eutrophication, and water contamination. Subsequently, mechanical factors such as building, digging, deposits, and recultivation of fallow land follow. In future, the use of herbicides will play a significant role in the decrease in species. The decrease in plant communities in Berlin can be quantified using the number of extinct and presumed extinct species (Table 3).

The strongest decline is shown by vegetation of the fields, bogs, waters and the acidic grasslands, with some 14-17% of the species lost, then follows moist meadows and woodland. The extinction of species in Berlin freshwaters is particularly marked. The extent of the decline in water plants is clearly seen if one considers that in the period under consideration, the surface areas of waters did not change, (with the exception of ponds). Despite this, there has still been a strong decline in number of species. Also for fields, the decline of coverage is not alone decisive. The ruderal vegetation finally shows a stronger increase of area – today nearly half of the city area – nevertheless a marked decline of native and archaeophytic species. Clearly, this loss (of species number) is by far outweighed by the arrival of neophytic ruderal plants.

Methods for Ecological Research with the Aim of Classification of Large City Areas

In contrast to the ecological approaches described later in which the condition of the city – or a part of a city – is characterised at a particular point in time (a "snap shot"), are the historical and historical – ecological methods in which the past events in a particular place are represented. From the summary of the observed data from the past, (flora and fauna lists, measurements, maps and so on), one can reconstruct the history of the flora, fauna, climate and soil (that is to say, the history of the landscape), and one can determine statistical characteristics (such as species numbers, percentage of neophytes and so on, and mean and range values for climate).

Historical Classification

When the available information permits a comparison with the former species pool, historical representations of changes in flora and fauna are very informative. Causes of the changes are introductions of species via trade and traffic and important changes in habitats. Gusev (1968) represented the changes in ruderaflora in the Leningrad area (now St. Petersberg) in the last 200 years. The recent ruderal flora comprises more than 350 species (excluding those found only rarely (that is to say 1–3 times)). Nearly half of the ruderal flora belongs to only three plant families: Compositae, Cruciferae, and Gramineae. Some 75% of the species are introduced. More than 130 species were first introduced, or brought in, in the last 200 years, including (e.g.) *Matricaria metricarioides* and *Convolvulus arvensis*, which are common today. In contrast, some ruderal plants became rare or extinct (for example *Bromus arvensis*).

A description of the changes in the synanthropic flora Posens between 1950 and 1970 was given by Zukowski (in Falinski 1971), analysing an increasing "continentalization" of the Flora Posens.

According to Scholz (1960), the number of naturalised neophytic ruderal plant species in Berlin were as follows: 20 in 1787, 51 in 1884, and 79 in 1959. One can determine that this amount is directly related to the human population size. In 1860, the dramatic increase in human population began, which corresponded to a sharp increase in the number of ruderal species (Fig. 1). The increase in urban weeds corresponds to a stronger decline of native and archaeophytic wild plants (Table 3).

Historical records can be provided not only by organisms, but also by changes in ecological factors. In the city of Berlin, investigations of temperature and groundwater were undertaken by Scherhag (1963) and Denner (1958) respectively. When earlier studies permit comparisons (for example in Berlin the maps of the phreatic level from 1870, 1916, 1929 and later, Denner), one can establish not only a temporal, but also a spatial structure of the city region.

Historical – Ecological Approach

Under the assumption that the oldest quarters of a city, today exemplify the oldest urban ecosystems, one can determine relationships between the different ages of settlement areas and their biotic dominant communities. A study of the flora of three small cities in Finland (Saarisalo-Taubert 1963) showed that the current distribution of the flora accompanying old settlements is determined by favourable edaphic and microclimatic conditions of the old settlements. Where these conditions are missing, these species are only present occasionally or rarely. The more fastidious the particular species are, the more suitable are the conditions in the older settlements. The so-called "friends of old settlements" could be absolutely new arrivals, or they could belong to the oldest species. Figure 2

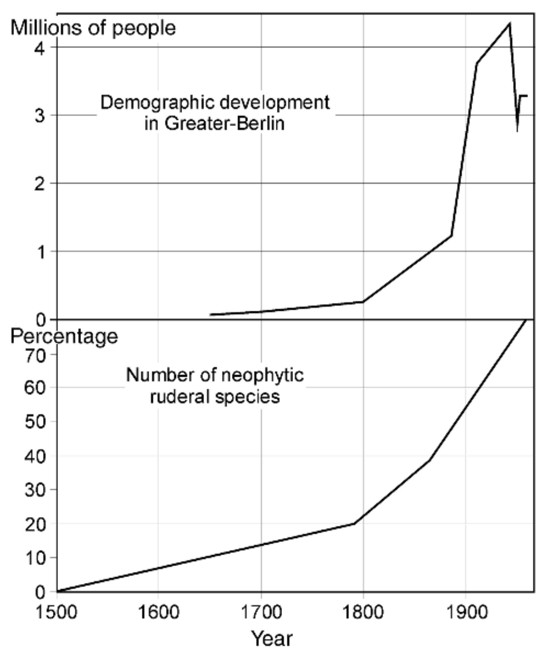

Fig. 1 Population growth in Berlin, and the number of neophytic ruderal species

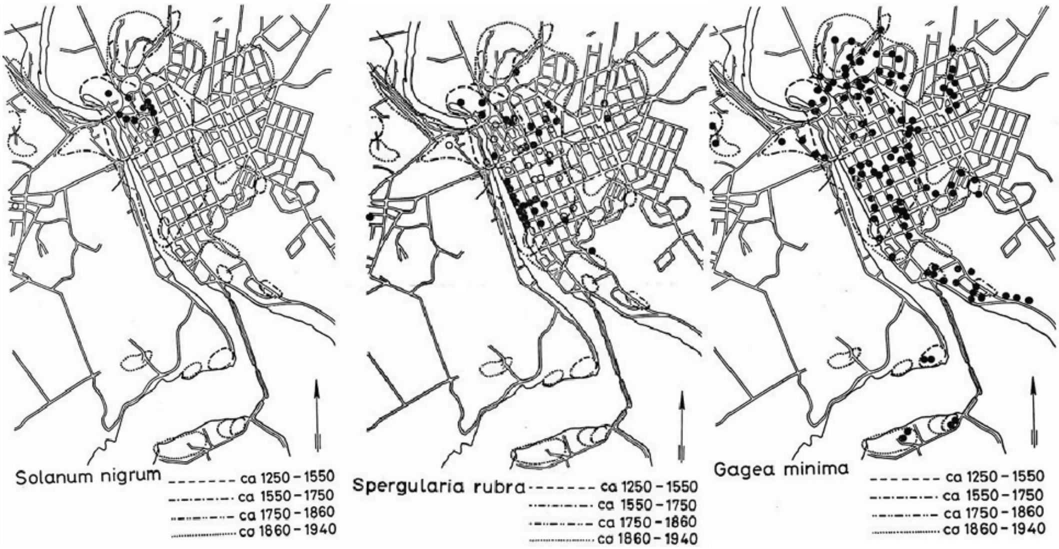

Fig. 2 Distribution of species in different areas of old settlements in the south Finnish city of Porvoo (after Saarisalo-Taubert 1963)

shows the distribution of species in different areas of old settlement in Porvoo. The distribution of species is similar in each of the three Finnish cities. However, one cannot necessarily carry over the knowledge of the indicator value of a single species, to other cities.

In general, the predominantly southern origin of indicator species has been proven. Zajac (in Falinski 1971) had interpreted the distribution maps of wall and garden plants in Bielsko-Biala (southwest Crakow), in connection with the city development, in relation to the distribution of other species, and the responsible critical recent climatic and edaphic factors.

In the studied biotopes, this floristic process corresponds to the phosphate mapping (Arrhenius 1931). Here, the appearance of sites with high phosphate contents in the soil corresponds to the appearance of settlements.

It is desirable, that similar studies be undertaken in central European cities that were not destroyed in the war. For many towns, and especially for large cities, the historical-ecological approach is not suitable. On one hand, due to war damage and more recent restoration, the oldest districts have been completely destroyed; and on the other hand, buildings are new.

Ecological Approaches

Classification According to Land Use

With studies of the flora, one can ascertain which species characteristically accompany certain land uses. Although the concept that, for example, meadow plants only grow on meadows, in the public spirit such relationships are not yet generally accepted for city and industrial biotopes. Almquist (1957) and Militzer (1961) have presented maps showing the spread of plants along railway lines. In Berlin for example, the distribution of a certain evening primrose (*Oenothera coronifera*), is linked to the railway lines. Sukopp and Scholz (1965) have reported about specific "canal plants" in Berlin. Such Berlin canal plants include the willow-leaved dock (*Rumex triangulivalvis*), and the garden angelica (*Angelica archangelica*). Other examples for the characteristic large city biotopes in Berlin are: tree of heaven (*Ailanthus altissima*) – spreading in industrial areas, butterfly bush (*Buddleja davidii*) – spreading in the inner city (where housing developed in the post-war years (Kunick 1970)), alien species from bird seed for the built-up areas, and bulbous meadowgrass *Poa bulbosa* (Sukopp & Scholz 1968) for bathing beaches and camps. A comparison of the areas with the same use, from the outskirts to the city centre, leads to formulation of ecological series**.** An example is given for recreational areas in Berlin (Fig. 3).

Nearly all the species groups decline with decreasing surface area and increasing recreational use, this disappearance may take place gradually, in other cases it may happen unevenly and abruptly. Only a few species are commonly encountered in the urban green spaces (*Euphorbia peplus*, *Galinsoga ciliata*, *Sisymbrium loeselii*, *Urtica urens*).

Spatial Classification

The natural classification can be of significant assistance in our understanding of the development of artificial landscape. However, today, natural borders often lie within settlements and are difficult to distinguish, and thus they alone are insufficient as classification characters.

With the classification of an urban agglomeration according to topographical units, it becomes evident that in addition to the present land use, additional regional influences operate to allow the combination of smaller mosaic sites into a larger whole. From the outskirts toward the city centre, there are clear gradients. “When the mosaic character of the biotopes remains, differences in the settlements populations can be determined, along with the proportion of a whole area occupied by single biotopes, especially those which are indicative of urbanisation” (Kühnelt 1955, pg. 35). In many cities, a clear zonation of the vegetation with epiphytic lichens and mosses has been determined (Ando & Taoda 1967; Barkman 1969). Generally, in the centre of a city only a few species are found, whereas in the periphery, the species show greater vitality, and more species can thrive. Observations which show a gradient away from and towards a city, include: climate data (Kratzer 1956, Scherhag 1963, Schlaak 1963), phenological data (Hoffmann, dissertation, Zacharias 1972), air pollution (Bracht 1960), frost damage (Joachim 1957), species which decrease in the city (summarised for mosses and lichens by Barkman 1969), and species which are only present in the city (“city plants” Gutte 1971, Sukopp 1971). A simple model of a city and the changes of its biosphere is given in Fig. 4, below.

Through urban building and economic activity, the city becomes divided into zones of densely built-up areas, row and edge buildings, and loosely built-up areas. The outskirts are characterised by allotment gardens and parks, as well as refuse dumps, rubble heaps, and sewage farms. In the surrounding countryside, fields and forests dominate. The urban building and economic activity result in pollution and warming of the air, changes in groundwater level, and large deposits. The volume of imported building materials, raw materials for manufacturing, and food, is greater than that exported, and this results in the ground level rising over time (numbers given by Peters 1954, Fels 1967). Due to the magnitude of the artificial (cultural) layers, eutrophication at many locations is combined with the artificial (cultural) layer, as well as condensation or sealing of the soil within the settlement. The eutrophication affects not only urban rubbish, refuse tips, and sewage farms, but also nearly all waters. In general, there is little space for vegetation within the city. However, exceptions include numerous street trees, and extended areas of ruderal vegetation on war damaged areas in the middle of the city Similarly, Kühnelt (1955) and Schweiger (1969) have delineated city zones based on their land use.

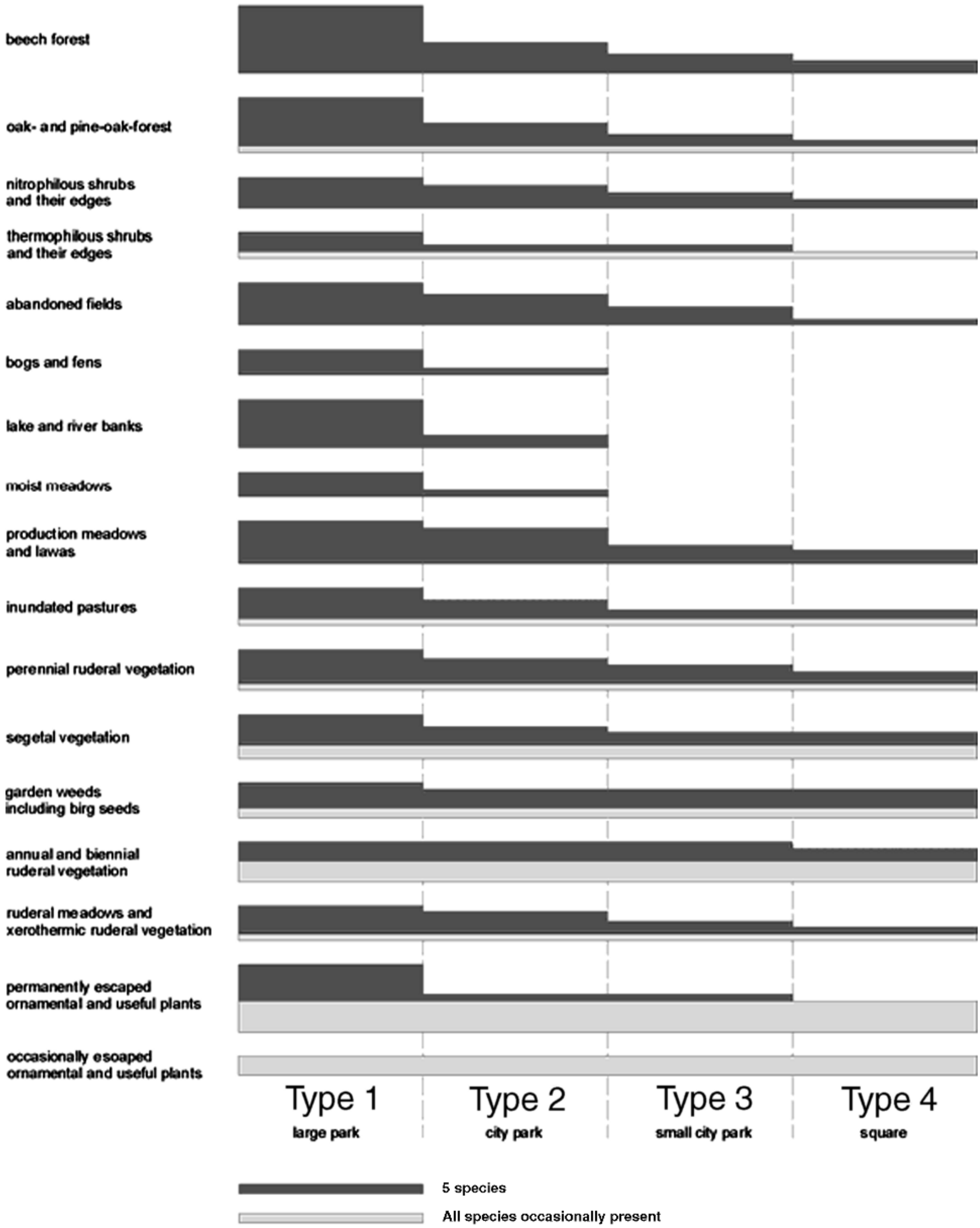

Fig. 3 Occurrence of species groups in different types of recreational areas in Berlin (from Kunick 1970). Large parks ranged from 60–140 ha and contained 250–450 species. City parks ranged from 10–25 ha and contained 120–150 species. Small city parks were 1 ha in size and held 60–140 species. Squares were 1 ha in size and held 40–120 species

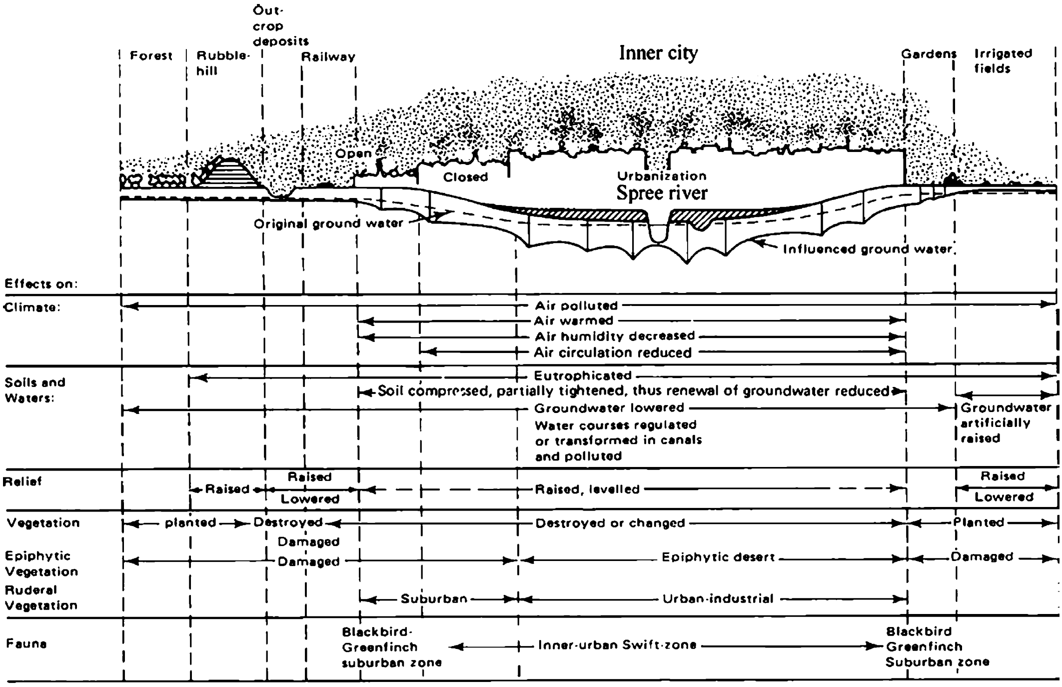

Fig. 4 Systematic portrayal of important changes in a city's biosphere

Classification with Berlin as an Example: Ecological Characteristics of the Berlin City Region.

Macro-Climate

According to the climate atlas of the GDR (German Democratic Republic), and the atlas of German environment, Berlin has an east German inland climate, with warm summers, relatively cold winters, and modest precipitation. The representative weather station for Berlin in Dahlem (at the edge of the densely built-up city centre), reported the following mean data for the period 1891–1951: July +18.3 °C, January −0.7 °C. The mean annual precipitation in the Berlin city area lies between 540 and 600 mm.

Urban Climate

The effects of the city on the climate have been summarised in a monograph by Kratzer (1956). The impact of the individual climate of such an extensive city as Berlin, for the naturalization of southern ruderal species has been demonstrated in detail by Scholz (1960). The following aspects detail the essential features of the city climate:

Higher Temperatures in Berlin Compared to the Surroundings

The inner districts of Berlin are, in all seasons, 1 °C warmer than the surroundings. The simultaneous temperatures during measurements by car are approximately ten times larger than with the mean temperature. According to the amplitude, the temperatures in the region in summer and winter are not significantly different, giving characteristic seasonal shifting in thermal differences. In winter, the inner city shows a slight condensation of the isolines. In summer, between 2/3 and 3/4 of the temperature amplitude is outside the built-up area. This shows seasonal separation of both main factors of the thermal differentiation: in summer the radiation balance dominates, in winter (when this amount is approximately 1/10 of the summer value), the artificial heat sources of the city (heat emitted from buildings) dominate.

Longer Growing Season in the City.

According to the climate atlas of the GDR, the mean frost-free time in the inner city of Berlin (for the period 1891–1930) was 206 days, in contrast to that in the outlying districts with means of 168 in Blankenburg, 169 in Spandau, and 184 in Dahlem on the borders of the city.

From phenological observations of trees (Günther 1959), one learns of an early start of the vegetation period in the city, which is in contrast to the situation in the surroundings (Kleinmachnow, south of Berlin), for example *Robinia pseudo-acacia* leaf shoots appeared five to six days earlier, and full flowering three to five days earlier (data for 1955–1958).

Detailed observations of blooming phases of street trees can be mapped (Zacharias 1972). In the centre of the city, the first blossoming of *Tilia euchlera* occurs eight days earlier than it does at the outskirts of the city. When the corresponding temperature differences are considered, there is a shifting of the blossoming date by about one week for each one degree Celsius. This corresponds well with what is known for larger scale phenological distributions of stronger temperature-determined phases, from for example central Europe. Trees in cold hollows, in forest clearings, and on forest edges blossom about two or more days later compared to the open sites. The strongest gradient (density of the phenological isochrones) occurs at the border between forest land and buildings, or between open sites and buildings. The relief of the land, especially in the forested areas, has less effect on the phenological data. This characteristic, is akin to that which we already know from the mean temperature data. An analysis of the phenological maps as mean temperature maps is possible.

Review of the research shows that the representation by profiles is well suited for characterisation of the city climate. The profiles are represented in Fig. 5, with the outskirts on the left, and the inner city on the right: dashed curves = temperature (distribution on summer radiation nights), continuous curves = phenological data in days (before or after representation station in the surroundings).

In considering the degree of correspondence between both curves, one should consider that for the phenological data the mean temperature of the preceding months is essential, but the temperature values depend on extreme nightly weather conditions. Thus, it is not surprising, that strong gradients do not always coincide. In both profiles, the phenological data show a smaller influence of the city than do the temperature measurements during radiation nights.

The connection of the thermic and phenological data with the different structural types of the city surface can be determined from the numbers on the lower edge of both representations (Fig. 5). The structural types are as follows: 1 open space such as fields, allotments, fallow land, green areas essentially without trees; 2 forests and similar growths; 3 forest settlements; 4–9 settlements and industrial land of increasing complexity, with density of building ranging from spread-out detached houses, to closely-packed 5 story high developments; 10–11 signify special locations (such as particular relief, or adjacent to water), which reflect the thermic and phenological characteristics.

The influence of the building construction is dominant everywhere. Furthermore, the cooling effect of even small open spaces is obvious, especially that if the Tiergarten park in the city centre. The different structures of the inner area are less clearly represented by the temperature distribution on radiation nights, than portrayed through the phenological data. In contrast, one can recognise a remote effect of neighbouring structures much better with phenological data than with the night temperatures. This addresses the expectations that the plants are also exposed to the temperatures during advection periods.

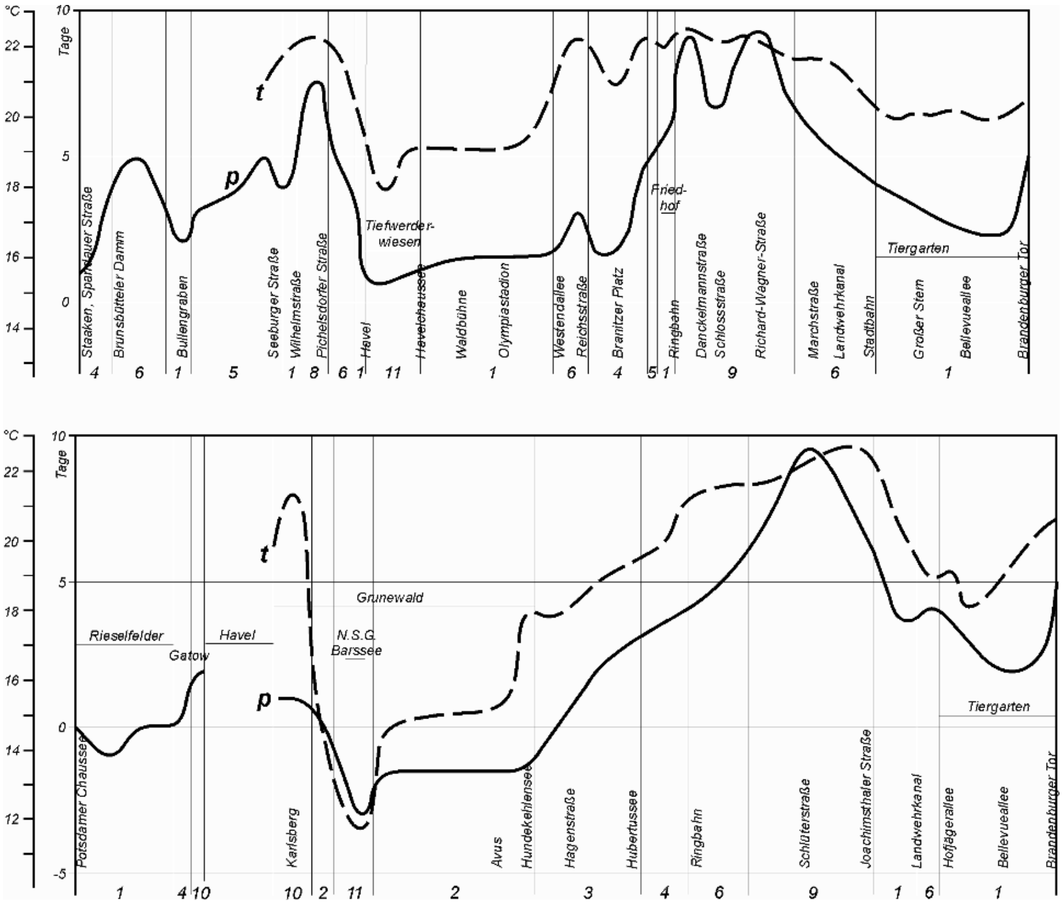

Fig. 5 Thermic and phenological profiles through western Berlin (from Zacharias 1972). Explanation in the text

These documents also facilitate a thermal estimate for the green areas. The cooling effect of large green areas also influences the surrounding built up areas. One should consider that in the means, the stronger wind periods are included. However, during these stronger wind periods, the high temperature of the city should hardly concern us. The overheating of the residential areas, especially during low wind radiation weather, may be very disturbing. This is often the case from the later afternoon into the night. The maps show that the larger green spaces (such as the park or zoo) can be about 4 °C colder at night than the surrounding area. However, only a small strip of the surrounding area is involved in the cooling down effect of the green space. The lower the wind velocity, the smaller is the effect of the green spaces on cooling their surroundings.

Relevant temperature effects of larger green spaces on the surrounding settlement can be expected only within a border of at least 100 m width. Such thermal edge effects – on the other hand – also arise from relatively small green spaces. With some caution, one can conclude that few large green spaces are not so suitable for obtaining favourable thermic effects, as are small or rather small green areas with the same surface area. The question of within which subdivision level the optimum for air purity actually lies, must still be determined. For urban planning decisions, the thermic effect of open spaces may carry relatively little weight. It is however to be noted, that the temperature distribution also permits conclusions to be drawn about the air exchange, and with it also related variables (such as degree of air pollution).

Soils

The soils of the city area are remarkably heterogeneous in composition, fine earth, humic content, and storage. There are all variations from fine earth and humus-poor rubble soils to humic garden and sandy soils with a small proportion of rubble.

From the work of Runge (1973), we can learn about wasteground soils. As in all young soils, the characteristics of the wasteground soils are strongly influenced by the materials from which they derive. The raw material is building debris, which was initially sorted by hand, and then by machine, after the World War II. During the sorting process, large brick pieces were separated from adhering mortar, and were used for reconstruction. This process still continues today "Enttrümmerung", with the debris being sorted on shaking riddles with a mesh size of less than 5 cm, and the bigger material being removed. By both hand and mechanical sorting, the material that remains is mostly brick and mortal debris, about 5 cm in diameter. This may be used for levelling at the same site, or elsewhere. There are frequently also considerable amounts of natural material mixed in with the manmade material. The places may remain unused for some considerable time, until they are newly built upon.

The levelled wastelands have subsequently been exposed to the influence of the urban environment in the 0–25 years since their initial formation, (which is in sharp contrast to the situation in a natural landscape). The environment influences the substrate, and its qualities are changed. Easily soluble materials are lost, and relatively insoluble materials become, both relatively, and absolutely, more concentrated. These processes lead to profile differentiation, and with that, to soil formation. The rapidity with which this occurs is surprising, and profile differentiation can be seen in rubble areas after 5–25 years. This is expressed in the fine earth fraction by the increase in calcium carbonate content in deeper horizons of 6 to 10%, by a pH value of 7.0 to 7.5, and a decrease of organic carbon of 3 to 0.5% (depending on the substrate). The short term or long term available nutrient content of the fine earth lies more often above, than below, the average values for natural soils. The high stone content (∼ 25–50%) in the wasteground soils is more effective for the water supply than for the nutrient supply. This forms the limiting factor, because the stones not only decrease storage volume, but also effect a faster water discharge in fissures and pore volume.

Flora and Vegetation

The results of phenological research correspond to floristic-vegetation research on classification of the urban area based on building usage. The density building conspicuously forms and classifies the physiognomy of the city. Statistical and city planning data are based on this, and it appears meaningful to use this data for the basis of the classification of a city. Four zones of Berlin can be identified (see Fig. 4).

Zone 1 – Closed build-up area - Characteristic for this zone are the rental tenement buildings dating from 1914, with poorly exposed backyards, and a minimum size of $5.3\,\mathrm{m} \times 5.3\,\mathrm{m}$ according to the building regulations of 1853 (at a building height of 22 meters!). The boundary of this zone is often arbitrary, and breaks down, where the building activity was interrupted by the outbreak of the World War I. However, in reality, the actual city formed "a closed unit" within the boundary formed by the circular railway, until the destruction of World War II. Within this area, the city reached its greatest dimensions, introducing a reorganisation of development schemes.

Zone 2 – Open built-up area - Within this zone are ribbon and margin development, and open residential buildings. A further characteristic is a higher proportion of ground that is covered by vegetation (higher than in zone 1). The population density drops sharply to an average of 150–200 inhabitants/ha. In recent years, the older residential suburbs have become increasingly mixed with new residential areas, uniform new housing developments, in which there is a high proportion of lawns, giving rise to the impression of a decorated quilt.

Zone 3 – Outskirts - This region is marked by the presence of rubbish dumps (rubbish tips some 117 m high, rubble heaps and so on), and in contrast by recreational facilities (parks, allotment gardens, summerhouse colonies, and sports fields).

Zone 4 – Surrounding countryside used for farm and forestry - West-Berlin has only a small portion of this zone, namely the Grunewald, which with its inshore waters, has become the most important local recreation area for the population. The areas of arable land in the west Berlin area have been sharply reduced in recent years, as expanded housing developments encroached and took over.

Floristic Classifications

For the current determination of species composition (both qualitative and quantitative) in individual city zones, the following method has been chosen (Kunick 1973):

For sample areas of the same size (1 km2), in single zones and their transition areas, as well as for representative land uses, the entire species composition of ferns and flowering plants which were not intentionally planted at those locations, were recorded. In order to obtain more exact information about the situation for an individual species, not only presence or absence was noted, but also the frequency per 25 patches 4 acres in size (equivalent to 1 block), and a shorthand outline for the location was assigned. In addition, the occurrence of a number of chosen species was mapped regularly in a chessboard fashion for surfaces distributed regularly over the city area.

When the species richness of flowering plants is considered in relation to the use of the land, the following pertain per km^2 (based on investigation of 18 areas):

Closely built-up - 400 species
Loosely built-up - 434 species
Outskirts - 440 species
Surrounding countryside - 250 species

There is a sharp increase in species richness from the surrounding countryside to the outskirts, of about 200 species per sampling area (km^2). Towards the city centre, the species number then decreases.

Similar results were found from research on city birds and the insect fauna (Erz, Mulsow, Schweiger), where – among all studied biotope types - the highest species number and the maximum population density, occurred in the highly structured residential areas. However, in the city centre, the results diverge, with extreme poverty of species in the fauna combined with high population densities, yet this does not apply to the flora in Berlin. Nevertheless, the species number per unit area in the closely built-up zone, is still higher than in the partly natural surrounding countryside. This is explained by the high percentage of immigrant species in the city centre.

For several cities, data are available for the species number and its changes, and a high proportion of neophytes are usually emphasised. This proportion of neophytes is usually between 30 and 50%, and can be used to indicate the intensity of the industrial-metropolitan influence (Sukopp 1969). The numbers calculated for Berlin are:

Zone 1	18%
Zone 2	12–18%
Zone 3	5–12%
Zone 4	< 5%

However, these numbers for Berlin need to be confirmed, and compared with other examples, before they are generalised. The rising percentage of neophytes (based on historical data), is related to differences in structure and "degree of naturalness" of the sites, and the intensity of cultural influences in the individual city zones, (as are differences in total number of species per unit area) (see Hemerobie, Table 4).

Table 4 Stages of cultural influence on ecosystems (degree of hemeroby)

	Criteria for Classification					
Hemerobiograde (terminology-after Julas)	Example	cultural influence	Substrates, soils, waters	Vegetation	Proportion of vascular plants that are neophytes	Loss of native vascular plants (per 1000 km ^{2})
metahemerobic	poisoned or biozide treated ecosystems; intact buildings and their interiors	very strong and one-sides; all organisms tend to get destroyed (whether intentionally or not)	characterized through defective or excessive organic substances, toxic substances, or extreme physical effects	only specialized species, or resistant phases; species numbers approach 0	–	–
polyhemerobic	pioneer communities with low competition, many short-lived ruderal communities	exist in short term and non-periodic formation and destruction of sites, new combination or extreme concentrations of ecological factors	greatly changed ruderal sites such as mortar soils, neopedon, substrates such as casting slag, mine heaps	greatly simplified communicty structure and destabilisation of the vegetation; extermination of less tolerant species	21 – (80)%	
euhemerobic	numerous perennial ruderal communities, field and garden weeds, lawns, forests of non-native trees	continuously strong	Changed (cultivated soils, rigosols)	vegetation and flora human conditioned (not "left to nature")	>6%	13–20%
mesohemerobic	meadows, pastures, forests of trees from different habitats, heathland, dry grassland	weaker or periodic	not totally changed or returns to the natural condition (e.g. deposits)	vegetation physiognomy human conditioned ("far from nature")	5–12 %	1–5%
oligohemerobic	forest with weak thinning or graded pasturing, salt meadows, growing dunes, growing bogs and fens,	not stronger than showing pristine features of the natural habitat	nearly no changes	actual vegetation corresponding to natural vegetation (near nature)	< 5 %	< 1 %

Table 4 (continued)

		Criteria for Classification				
Hemerobiograde (terminology-after Julas)	Example	cultural influence	Substrates, soils, waters	Vegetation	Proportion of vascular plants that are neophytes	Loss of native vascular plants (per 1000 km ^{2})
	some water plant communities					
ahemerobic	water, fen and rock vegetation in some parts of Europe, in Central Europe only in parts of the alpine vegetation	does not exist		vegetation not touched by people (natural vegetation)	0 %	0 %

Classification According to the Distribution of Individual Species

Mapping of individual species in West Berlin shows that there are numerous species which have a clear concentration in the city and or in outlying districts, in contrast to other species which occur more or less everywhere with similar frequency. This may be accounted for by the fact that certain species are bound to particular land uses (such as lawns and gardens with walls), and when the land use changes, the plants no longer thrive. Alternatively, it is conceivable that, independent of the present land use, comprehensive city influences enhance or impede the distribution of higher plants, as has been demonstrated several times for lichens.

In Berlin, one can speak of a *Tussilago*-*Chenopodium botrys*-*Sisymbrium loeselii* city centre, which is subdivided into parts with the most intense war damage (characterised by intensified occurrence of *Diplotaxis tenuiflora* and *Buddleja davidii*), which are distinguished from those quarters with tenement buildings that were not seriously damaged (with *Commelina communis*, *Parietaria pennsylvanica* and wild *Ailanthus* (Contributions to ecology of *Chenopodium botrys* I–VI, Kunick 1970, Sukopp & Scholz 1964).

The open built-up zone is characterised by, for example *Atriplex oblongifolia*, *Lamium purpureum* and *Veronica* spec. div.. Within this zone, *Clematis vitalba* is associated with boulder clay, and occurs less frequently on sand. The surrounding countryside is distinguished from the other zones by the appearance of *Pinus silvestris*, *Prunus serotina* and other forest plants. For a comparison with the distribution pattern of an animal species, the collared dove can be considered: it is absent from the city centre, at a maximum at the edges of the built-up areas with street trees, common near grainfields, and uncommon near closed forest areas (Löschau & Lenz 1967).

Classification According to Biotic Communities (Thus far Only for Special Taxa)

A classification according to bird communities exists for the urban area of Hamburg, and will probably be valid for other northwest German cities (Mulsow 1968). Mulsow subdivides the house sparrow – blackbird city landscape as follows:

A. House sparrow – swift – city centre

1 Industrial – commercial zone black redstart – field landscape
2 Swift – old buildings quarters
3 Crested lark – new building quarters

B. Blackbird – greenfinch – outskirts

1 redstart – residential quarter
2 tit – dunnock – park landscape
3 lesser white throat – garden landscape

For the urban area of Berlin, a temporary classification, according to plant communities can be described:

Zone 1: *Chenopodium botrys* – community, Chenopodietum ruderale,
Sisymbrietum altisimi as pioneer community, with a tendency for the development of ruderal semi-dry grassland (Poa – Tussilaginetum) and false acacia bushes (succession scheme Fig. 6).
A vegetation map of a characteristic part of the destroyed inner city of Berlin, with levelled wastelands is described by Sukopp (1971).
Zone 2: Hordeetum murini , predominant *Acer-Ulmus* young growth, with a tendency for development of a Alno-Padion forest community.
Zone 3: Urtico-Malvetum, Leonuro-Ballotetum
Zone 4: Sand – dry grassland, Pino-Querceten changed by forestry (with *Prunus serotina*).

Finally, we may inquire as to the purpose and utility of such an analysis of the biotic communities and their locations in a city, and the following observations can be made: due to the rapid increase in land development in Berlin, and the increasing urbanization of the world, the effects on organisms – plants, animals, and humans – must be observed and monitored. Most investigations about such questions usually begin only after the first bad consequences are manifest. Today, landscape conservation and urban green space management usually limp behind city development. In the present study, foundations are created to facilitate evaluation of the changes in landscape and biotic communities. If it succeeds in uniting individual research results into a comprehensive statement about the quality of life of the city biotopes, there will then be – in future – a basis for rational planning decisions; a necessity that is already urgent today.

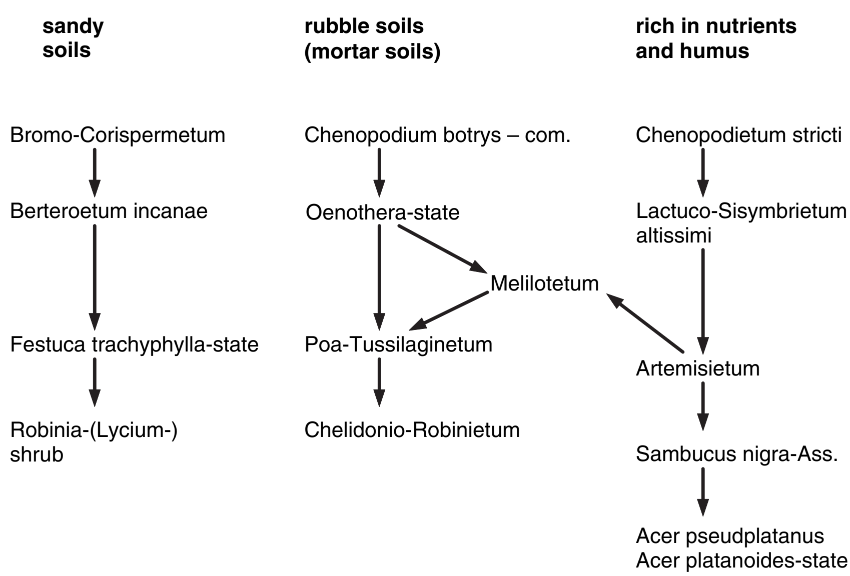

Fig. 6 Vegetation development at locations in the inner city of Berlin

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